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Hydropower–water and renewable energy in Turkey: Sources and policy

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Abstract

Turkey's energy consumption has been growing much faster than its production. It forces Turkey to make a rapid action to supply energy demand. From the viewpoint of primary energy sources (petroleum and natural gas), Turkey is not a rich country, but it has an abundant hydropower potential to be used for generation of electricity. Hydropower is the most important kind of renewable, sustainable energy and a proven technology for electricity generation. The aim of this paper is to discuss sources and policy of hydropower, water and renewable energy in Turkey and compares the hydropower application with Europe.

Keywords: Renewable energy; Energy and water policy; Hydropower; Turkey

Contents

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1. Introduction

Energy is considered to be a key factor in the generation of wealth and also a significant component in economic development in Turkey as in other countries. This makes energy resources extremely significant for energy countries in the world. Because of social and economic development of Turkey, the demand for energy and particularly for electricity is growing rapidly. The main indigenous energy resources are hydro and lignite. Turkey has no big oil and gas reserves. Almost all oil and natural gas is imported, as is high quality coal [1]. As we move into the 21st century, Turkish economic prosperity is driving the consumption of energy to record levels, with electricity consumption anticipated to increase at rates faster than overall energy supply (see Fig. 1).

In Turkey, electricity is produced by thermal power plants, consuming coal, lignite, natural gas, fuel oil and geothermal energy, and hydropower plants (HPPs). There is no nuclear power in Turkey as yet. However, according to the long-term energy plan, the first nuclear power plant with a capacity of 1000 MW will be operating in 2010.

Water is such a natural substance that cannot be substituted by any material and the living beings are dependent on it. But as a result of rapid growth of population and the expansion of irrigated agriculture and industry, water resources are being stressed both quantitatively and qualitatively. In addition, pollution is making more of the water that is available to us unfit for use. As a consequence of the decrease in water resources, water is referred in a growing literature as the resource which will bring combatants to the battlefield in the 21st century [2].

Energy and water are often said to be the main cause of future problems. In that regard, Turkey has a strategic location in the region since it is close to oil- and natural gas-rich countries which may face water scarcity sooner or later. Therefore, utilization of water resources at the most appropriate and efficient way is crucial. This is where engineering and technology come into play along with capital requirement.

2. Renewable energy sources and policy in Turkey

2.1. Renewable energy policy

Energy constitutes one of the main inputs for economic and social development. In line with the increasing population, urbanization, industrialization, spreading of technology and rising of wealth, energy consumption is increasing. Energy consumption and consequently energy supply at minimum amount and cost is the main objective, within the approach of a sustainable development that support economic and social development and that have destructive impact on the environment at the minimum level. Turkey's energy policy is based on the following items:

- Meeting long-term demand using public, private, and foreign capital.
- Accelerating privatization activities in the energy sector.
- Taking into consideration supply costs of energy imports.
- Meeting demand as much as possible through indigenous resources.
- Diversifying energy supplies and avoiding dependence on a single source or country.
- Adding new and renewable sources (geothermal heat, solar, wind, etc.) as soon as possible to the energy supply system.
- Ensuring sufficient, reliable and economic energy supplies on time.
- Ensuring energy security of supply.
- Implementing measures for energy efficiency.
- Planning energy research and development activities to meet requirements.
- Minimizing losses in energy production, transmission, distribution and consumption.
- Protecting the environment and public health in the production of energy.

As basic strategy, improvement of domestic production by increasing efficiency of plants by rehabilitation, diversification of energy sources to secure fuel supply, accelerating the existing construction programs, initiation of new investments are chosen to achieve these energy policies. As Government's financial resources are not enough to achieve these objectives, acceleration of private investments is essential.

2.2. Renewable energy country profile

Renewable energy resources (sun, hydroelectric, biomass, wind energy, ocean and geothermal energy) are inexhaustible and offer many environmental benefits over conventional energy sources. The following definition could be considered a basic one: renewable energy sources are the energy sources formed on the basis of constantly existing or periodically originating processes in the nature as well as in flora and fauna life cycle and vital function of the human society [3].

Each type of renewable energy also has its own special advantages that make it uniquely suited to certain applications. Almost none of them release gaseous or liquid pollutants during operation. In their technological development, the renewable ranges from technologies that are well established and mature to those that need further research and development. The other important factor of renewable resources is to create new employment opportunities. Turkey's energy supply is based on a balanced mixture of energy sources, in which renewable sources in 2006 represented 31% of the primary energy share and primary energy production and consumption have reached 34 and 135 mtoe (see Table 1), respectively. Turkey is an energy importing country, more than half of the energy requirements have been supplied by imports. Natural gas has the biggest share in total primary energy consumption. Renewable except hydraulic and waste, have only very minor shares in power generation in Turkey. Total share of renewable in total primary energy supply has declined, owing to the declining use of non-commercial biomass and the growing role of natural gas in the system.

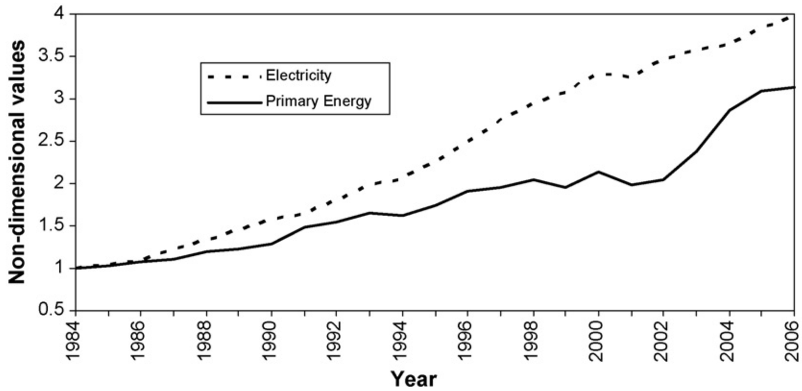


Fig. 1. Time-evolution of primary energy and electricity consumption of Turkey.

2.3. Sectorial overview

2.3.1. Hydropower

Turkey does not have enough primary energy sources such as petroleum and natural gas, but has a huge hydropower potential. Turkey's second largest energy source after coal is hydro. The Turkish government hopes that hydrocapacity will expand to 35,000 MW by the year 2020. The government expects the construction of 332 more hydroplants in the long-term to make use of the potential remaining hydrosites. This would bring the number of hydroplants to 485, and add more than 19 GW of capacity to the hydrosystem. This increase in the hydrogenerating capacity includes the southeastern Anatolia Project (GAP) that covers 1/10th (74,000 km^2) of Turkey's total land area, one of the largest hydro developments ever undertaken. Upon its completion, GAP will have an installed capacity of 7476 MW. The construction of all these new dams requires an investment of more than US$ 30 billion [4].

2.3.2. Wind energy

Wind energy is the fastest growing energy source in the world and wind power is one of the most widely used alternative sources of energy today. It is a clean and renewable source of electricity [5]. With an annual average wind speed and power density of about 2.5 m/s and 25.8 W/m^2, respectively, the western, northern and southeastern coasts of Anatolia have been identified as very favorable locations for wind power generation in Turkey. Technical wind potential of Turkey is given as 88,000 GW and the economic potential is estimated as 10,000 MW [6]. The current production status of wind energy projects in Turkey is between 727.96 and 817.96 MW [7]. A detailed wind speed assessment will have to be undertaken before a more accurate assessment of wind potential can be made. The majority of wind energy projects are concentrated in the Aegean (16 projects) and Mediterranean regions (9 projects). The installed capacity of wind energy is expected to reach 600 MW by 2010 and 1000 MW by 2020. Theoretically, Turkey has 160 TWh a year of wind potential, which is about twice as much as the current electricity consumption of Turkey [5].

2.3.3. Geothermal energy

Turkey is the seventh richest country in the world in geothermal potential for its direct use and for electricity generation [8]. It is located on the Alpine–Himalayan organic belt, having one-eighth of the world's geothermal potential. Turkey has 170 geothermal fields over 400 °C temperature and around 1000 hot and mineralized natural self-flowing springs and they are located mainly on West, Northwest and Central Anatolia. Turkey is ranked as fifth biggest geothermal energy user for heating and hot spring purposes after China, Japan, USA and Island [9]. Turkey's geothermal fields are more available to direct-use applications, since 95% of geothermal fields are low–medium enthalpy resources. Gross geothermal

Table 1
Energy production and consumption in Turkey (mtoe[a])

Energy sources	Energy produced	% of total production	Energy consumption	% of total consumption
Coal and lignite	21.22	62.50	36.24	26.87
Oil	1.58	4.65	41.68	30.90
Natural gas	0.56	1.65	46.37	34.39
Com. renewable and wastes[b]	5.26	15.50	5.26	3.88
Nuclear	–	–	–	–
Hydropower	4.32	12.72	4.32	3.20
Geothermal	0.73	2.15	0.73	0.55
Solar/wind/other	0.28	0.83	0.28	0.21
Total	33.95	100	134.82	100

[a] Million tonnes of oil equivalent.
[b] Comprises solid biomass, biogas, industrial waste and municipal waste.

Table 2
Capacities in geothermal utilization in Turkey (2006) [10]

Geothermal utilizations	Capacity
District heating	827 MW_t
Balneological utilization	402 MW_t
Total direct use	1229 MW_t
Power production	20.4 MW_e
Carbon dioxide production	120,000 t/year

Table 3
Some of Turkey's high enthalpy geothermal fields

Geothermal field	Temperature (°C)
Denizli-Kizildere	242
Aydın-Germencik-Omerbeyli	232
Canakkale-Tuzla	174
Kutahya-Simav	171
Aydın-Salavatli	162
Manisa-Salihli-Caferbeyli	155
İzmir-Seferihisar	153
İzmir-Balcova	126
Ankara-Kizilcahamam	106
Afyon	106

potential of Turkey is given as 31,500 MWt, corresponding to 5 million residences heating whereas the economic potential for heating purposes is estimated to be 2843 MW but the share of geothermal energy production, both for electrical and thermal uses is 1229 MW (Table 2).

Some of the geothermal fields of Turkey are given in Table 3. Aydin-Germencik, Denizli-Kizildere, and theoretically Nevsehir-Acigol fields have the highest enthalpy among all and can be used both for electricity generation and district heating applications. These fields may be evaluated if the government offers the financial and/or institutional support that is required for successful development [11]. Electricity generation projections of Turkey are also 500 MW from Germencik, Kizildere, Tuzla and several of the other fields by the year 2010 and 1000 MW by 2020 [12].

2.3.4. Solar energy

Turkey lies in a sunny belt between 36°N and 42°N latitudes. The yearly average solar radiation is 3.6 kWh/m^2 day and average sunshine duration is 2640 h, corresponding to around 30% of the year. Solar energy potential in Turkey is shown in Table 4.

Solar energy technologies are not extensively used, except for solar water heaters (SWH). Turkey has a total installed capacity of 8.2 million m^2 collector area with a total energy production of 287,000 toe, as of 2001. In Turkey solar energy has a technical potential of 8.8 mtoe electricity generation and 26.4 mtoe heating capacity. The SWH industry, in Turkey, is well developed and main system produced is the thermosyphon type and consist of two flat plate solar collectors having an absorber area between 3 and 4 m^2, a storage tank with capacity between 150 and 200 l and a cold water storage tank, all installed on a suitable frame. SWH use is limited to supply domestic hot water for about 19% of the housing stock.

At present, Turkey does not have an organized commercial and domestic photovoltaic (PV) programme [13,14], because the government has no intention in PV technology. On the other hand, there is good potential for PV applications in the local market since the country is enormously suitable due to high rates of solar radiation and available land for PV applications.

2.3.5. Biomass

Biomass energy includes fuel wood, agricultural residues, animal wastes, charcoal and other fuels derived from biological sources, are used by approximately half of the world's population as cooking and/or heating fuel and currently accounts for about 14% of world energy consumption. Biomass is the main source of energy for many developing countries, providing more than 90% of the energy supply in some developing countries. Fuel wood and other biomass fuels are handled and combusted primarily by women, who are largely responsible for repetitive chores, such as cooking, and are often involved in any household industries. Women and children generally have the main responsibility for collecting fuel. It is estimated that Turkey has a theoretical gross biomass potential of 135–150 mtoe/year, and a theoretical net potential of 90 mtoe/year. But the economical potential is given as 25 mtoe/year. The total recoverable bio-energy potential is estimated to be about 16.92 mtoe as given in Table 5. The estimate is based on the recoverable energy potential from the main agricultural residues, livestock farming wastes, forestry and wood processing residues and municipal wastes.

Table 4
Solar energy potential for seven regions of country

Region	Radiation energy average (kWh/m^2 year)	Sunshine duration period				
		Maximum (kWh/m^2 year)	Minimum (kWh/m^2 year)	Average (h/year)	Maximum (h/month)	Minimum (h/month)
Southeast Anatolia	1492	2250	600	3016	408	127
Mediterranean	1453	2112	588	2924	360	102
Central Anatolia	1434	2112	504	2712	381	98
Aegean	1407	2028	492	2726	371	96
East Anatolia	1395	2196	588	2694	374	167
Marmara	1144	1992	396	2528	351	88
Black Sea	1086	1704	408	1966	274	84

Table 5
Total recoverable bio-energy potential in Turkey [15]

Type of biomass	Energy potential (ktoe)
Dry agriculture residue	4,560
Moist agriculture residue	250
Animal waste	2,350
Forestry and wood processing residues	4,300
Municipality wastes and human extra	1,300
Firewood	4,160
Total bio-energy	16,920

3. Water sources and policy in Turkey

3.1. Water policy

The first hydropower plants were constructed in the 1890s, and hydropower became an important new benefit that could be derived from a country's water resources. Governments were involved right from the start; they needed to adjust their water policies and regulations, so that this new use of water resources would fit in harmoniously with traditional users such as irrigation, shipping, fisheries, etc. Then as now, Governments had to ensure that the development of water resources was of overall benefit to society, and took account of the interests of all stakeholders [16]. The past provides copious evidence of the influence of water on the growth of civilization. The strong and growing dependence of civilization upon the development and appropriate management of water resources had appreciated the person developing water resources as carrying out a genuinely sacred mission. Turkey views water as a catalyst for co-operation rather than a source of conflict. The objectives, principles and policies of the country on water issues are given as the following:

- Constructing the lacking wastewater infrastructure for the supply of sufficient and healthy drinking water.
- Protecting underground and surface water resources against pollution.
- Encouraging the usage of treated wastewater in agriculture, households and industry.
- Increasing the urban infrastructure investments in line with urbanization and improving living quality.
- Developing action plans for immediate supply of drinking water and disposal of wastes in case of likely damages in infrastructure networks to be caused by natural disasters.
- Ensuring co-ordination among the institutions operating in utilities sector.
- Preventing illegal use of water and reducing network leakage.
- Encouraging privatization of water and sewerage facilities and restructuring the municipalities as supervisory mechanisms.
- Re-identifying water and wastewater standards according to EU standards and performing legal arrangements as regards the improvement, use and preservation of water resources.

As stated before, there are trans-boundary rivers in Turkey which constitute 36% of the country's water resources. Hence, the issue of trans-boundary waters is very sensitive and political in Turkey and is the responsibility of Ministry of Foreign Affairs. Turkey's policy regarding the use of trans-boundary rivers is based on the following principles:

- Trans-boundary waters should be used in an equitable, reasonable and optimum manner.
- Equitable use does not mean the equal distribution of waters of a trans-boundary river among riparian states.
- Each riparian state of a trans-boundary river system has right to make use of the water in its territory.
- Riparian states must make sure that their utilizations of such waters do not give significant harm to others.

Turkey defines Euphrates and Tigris rivers as "trans-boundary rivers" and not as "international rivers" as it is claimed to be by Syria and Iraq. Turkey has the following policies regarding these rivers:

- The principle of sharing the benefits at basin level should be pursued.
- The combined water potential of the Euphrates and the Tigris rivers is, in view of the Turkish authorities, sufficient to meet the needs of the three riparian states provided that water is used in an efficient way and the benefit is maximized through new irrigation technologies and the principle of "more crop per drop" at basin level [17].
- The variable natural hydrological conditions must be taken into account in the allocation of the waters of the Euphrates and the Tigris rivers.

Turkey believes that water should be a source of cooperation among three riparian states which will improve the life quality of the people. Turkey designed a "Three Staged Plan" which is based on the fact that the Euphrates and the Tigris make up a single trans-boundary river system and envisages the preparation of common inventories of water and land resources for a final allocation of water between the riparian states [17].

In order to develop the "holistic, integrated perspective" [18] that water resource policy analysis requires, it is essential to appreciate the interrelationships and interdependencies that have evolved over time. It is also essential to understand the consequences of alternative policies. When such an understanding is absent, the water resource policy development process becomes myopic. The result is a piecemeal approach to policy [19]. Such an approach is inadequate. A comprehensive, integrated approach is required.

3.2. Water sources country profile

Turkey is located in a region where sufficient amount of water has never been available. Contrary to the general belief, Turkey is not a country with abundant water resources. The annual per capita water potential is at present 1500 m^3 but expected to reduce to 1000 m^3 with the estimation of 100 million populations in the year 2030. When the countries such as Israel, Jordan, Palestine, Qatar, Yemen are taken into

consideration with 150–400 m^3/year per capita water potential, Turkey seems to be ''water-rich'' in the region in comparison to those countries. But being a ''water-rich'' country requires having 8000–10,000 m^3/year water per capita. Thus, Turkey cannot be considered a ''water-rich'' country and its per capita potential is nearly the same as that of its neighbours Iraq (2000 m^3/year) and Syria (1400 m^3/year) [20]. Although Turkey has an adequate amount of water in general, it is not always in the right place at the right time to meet present and anticipated needs. The rivers in general have irregular regimes, and natural flows cannot be taken directly as usable resources. The average annual precipitation, evaporation and surface runoff geographically vary greatly [9,21]. On the other hand, Turkey has 665,000 ha of inland waters, excluding rivers and small streams. There are 200 natural lakes, with a total area of 500,000 ha, and 775 dams, lakes and ponds with a total surface area of 165,000 ha [9].

In Turkey, while the gross water potential per capita was 3980 m^3 at the beginning of 1960, this fell to 2840 m^3 at the beginning of 2000 and it is estimated to decrease to 2000 m^3 in 2010 as a result of population increase. However, when evaluated on the basis of the average annual exploitable potential, this figure will be about 1300 m^3. Thus, as understood from these figures, some regions of the country will face water scarcity in drought seasons and Turkey will become a water-deficit country in the future [9,21]

The annual average precipitation in Turkey is 643 mm/m^2, corresponding to 501 km^3 (51 billion m^3 (bcm)) annual rainfalls. Only 186 bcm of this amount forms the surface runoff. Together with 7 bcm water coming from neighboring countries, gross water potential of Turkey is 193 bcm. But in the framework of technical and economical conditions, surface runoff water amounts to 98 bcm and with the groundwater potential of 12 bcm, the total annual consumable potential equals to 110 bcm (Fig. 2).

Turkey's water resources are considered in 26 drainage basins. However, water resources of the country display a distribution which is temporally and geographically unbalanced. Most of the country's water potential lies in the southeast (28.5%) and Black Sea Region (8%). The drainage basins of Turkey and the water potential by drainage are given in Table 6. The most important rivers are the Euphrates (Firat) and Tigris (Dicle) rivers which are trans-boundary rivers originating in Turkey and discharging into the Persian Gulf. The other trans-boundary rivers of the country are Asi, Meric, Aras, Arapcay, and Coruh.

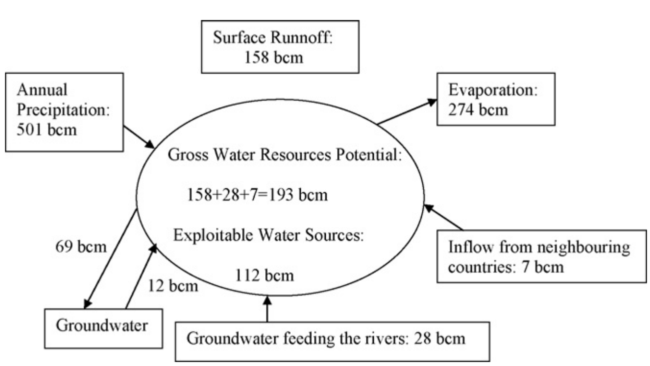


Fig. 2. Water budget of Turkey [9].

Table 6
Characteristics of Turkey's drainage basins

Drainage basin	Average runoff (km^3)	Percentage of potential (%)	Annual average yield (l/s km^2)
Meric-Ergene	14.5	0.7	2.9
Marmara Sea	24.1	4.5	11
Susurluk	23.7	2.9	7.2
Northern Aegean	12.4	1.1	7.4
Gediz	17.1	1.1	3.6
K. Menderes	7.10	0.6	5.3
B. Menderes	24.9	1.6	3.9
Western Mediterranean	22.6	4.8	12.4
Antalya	14.5	5.9	24.2
Burdur Lake	8.7	0.3	1.8
Akarcay	8.3	0.3	1.9
Sakarya	56.5	3.4	3.6
Western Black Sea	29.6	5.3	10.6
Yesilirmak	36.1	3.1	5.1
Kizilirmak	76.2	3.5	2.6
Konya (closed)	55.5	2.4	2.5
Eastern Mediterranean	22.4	6	15.6
Seyhan	20.7	4.3	12.3
Asi	10.8	0.6	3.4
Ceyhan	21.2	3.9	10.7
Firat	120.9	17	8.3
Eastern Black Sea	24	8	19.5
Coruh	19.9	3.4	10.1
Aras	27.5	2.5	5.3
Van Lake	15.2	1.3	5
Dicle	51.5	11.5	31.1
Total	765.9	100	

In order to develop water resources of the country, totally 547 dams were constructed till 2004. Meanwhile, 536 dams were constructed by DSI and the rest by private sector. Furthermore, totally 133 HPPs and 659 ponds were constructed till 2004. The construction of 51 of those HPPs was done by DSI and 82 of them by private sector. Although the number of projects completed to date is not negligible, Turkey is only one-third way through in developing its water resources potential. Table 7 shows the targets of DSI to develop water resources till the year 2030. According to DSIs calculations, irrigation will be developed 57%, hydroelectric 35% and drinking and industry water 27% till 2030.

3.2.1. Sectoral water consumption

As stated before, although the available water per capita in Turkey is one-fifth of the water-rich countries, there is a

Table 7
Targets of Turkey for water resources development (till 2030)

Development fields	Status in 2004	Targets for 2030	Development rate (%)
Irrigation (million ha)	4.8	8.5	57
Hydroelectric power (TWh)	45.2	127.8	35
Drinking and industry water (bcm)	10.5	38.5	27

Table 8
Sectoral water consumption (for the years 2003 and 2030)

Sector	2003 (bcm)	Percent (%)	2030 (bcm)	Percent (%)
Irrigation	29.6	74	71.5	65
Drinking water	6.2	15	17	15
Industry	4.3	11	21.5	20
Total	40.1	100	110	100

prevailing belief that Turkey has abundant water resources. The impression of Turkey having huge water potential derives from the fact that the country is not at present in a position to fully utilize its water resources [17]. In the year 2003, total water consumption of Turkey was 40.1 bcm which indicates that only 36.5% of the 110 bcm economic water potential could be utilized. The biggest part of the water was consumed for irrigation (29.6 bcm), followed by drinking water (6.2 bcm) and industry (4.3 bcm) sectors in 2003. It should also be underlined that irrigation is not only the largest component of water consumption in Turkey but also the greatest consumer of funds allocated for water resources projects. Till the year 2030, Turkey plans to utilize all water resources at maximum rate and finally reach full utilization in that year. Current sectoral water consumption and projections for the year 2030 are given in Table 8.

3.2.2. *Drinking water supply system of Turkey*

According to 2001 statistics, there are 3215 municipalities in Turkey and the number of municipalities having drinking water network is 2925. In other words, 91.5% of population was served by drinking water network in municipalities in 2001. Regarding to drinking water purposes 4.42 bcm was abstracted from different resources but only 37.87% of abstracted water was treated before distribution [9]. In the year 2001, it was recorded that there are 223 municipalities in Turkey with drinking water treatment plants. Drinking water statistics are given more in detail in Table 9.

It should also be noted that 61% of water for drinking water supply is abstracted from groundwater, 35% from springs and 4% from surface waters. Lakes, dams and artificial lakes have been used for drinking water purposes, since the ground waters are insufficient to meet the water demand of the country. It should be underlined that, per capita drinking and usage water consumption in Turkey has been increasing. According to DSI statistics, per capita water consumption was 98 l/day in 1980, it reached 192 l/day and 210 l/day in 1990 and 2000, respectively.

Other than municipalities there are 78,625 settlements in rural area, 36,527 of which are villages and the rest is sub-village settlements according to 2002 statistics. Having scattered and fragmented settlements in rural areas causes problems in physical and social infrastructure services to be delivered. Nevertheless, work towards water supply and sewerage networks and wastewater treatment plants, and improvement of standards is being carried out in rural areas. It is stated in National Development Plan of Turkey (2004–2006) that 89% of the villages have hygienic and adequate drinking water, but 8% of the villages have hygienic but inadequate water. Furthermore, 3% of the villages do not have clean drinking water. Seventy-six percent of the villages that have hygienic drinking water also have water delivery network system. Statistics of DIE from the year 1998 about treated water in rural areas shows that less than 1% of the villages drink treated water and 63.16% of the villages drink chlorinated water. The main resource of water supply in villages has been springs (86.07%), followed by wells (12.18%).

Table 9
Municipality drinking water statistics (2001) [9]

Total number municipalities	3,215
Population of municipalities	53,377,431
Ratio of municipality population to total	78.7
Number of municipality having drinking water network	2,925
Population served (%)	91.5
Total amount of water abstracted (m^3/year)	4,419,837,900
Number of municipality having water treatment plant	223
Number of drinking water treatment plant	110
Population served (%)	38.4
Capacity of drinking water treatment plants (m^3/year)	2,963,076,180
Physical treatment (m^3/year)	583,559,600
Conventional treatment (m^3/year)	2,379,516,580
Amount of water treated (m^3/year)	1,673,648,741
Physical treatment (m^3/year)	455,847,100
Conventional treatment (m^3/year)	1,217,801,641
Number of units responsible for operating drinking water network	3,215
Municipality unit	2,966
Municipality firm	20
Dependent establishment	147
Private sector	2
Union	80

4. Hydropower

Hydropower is a proven technology for electricity generation, contributing with almost 20% to the fulfillment of the planet electricity demand. Hydroturbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and water discharge. Hydropower continues to be the most efficient way to generate electricity. Modern hydroturbines can convert as much as 90% of the available energy into electricity. The best fossil fuel plants are only about 50% efficient. Hydropower is also renewable because it draws its essential energy from the sun and particularly from the hydrological cycle.

Summarizing, some of the main beneficial characteristics of hydropower are the following [22,23]:

- Its resources are widely spread around the world. Potential exists in about 150 countries and about 70% of the economically feasible potential remains to be developed.
- It is a proven and well-advanced technology, with more than a century of experience, with modern power plants providing the most efficient energy conversion process (490%) that the mankind has developed up to now.
- The production of peak load energy from hydropower allows the best use of base load power available from other less flexible electricity sources.

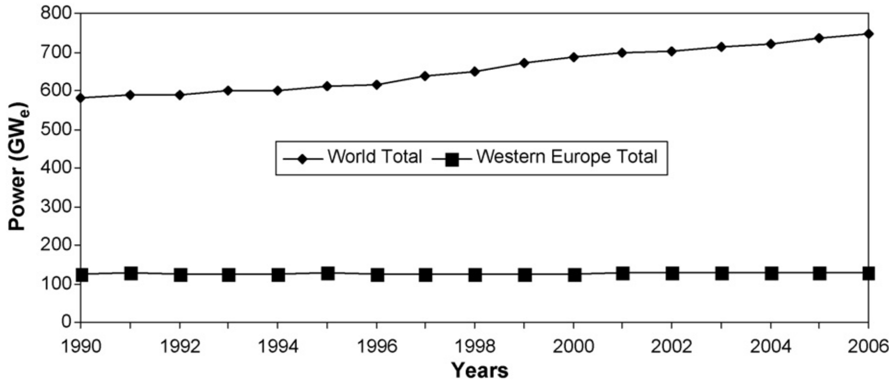


Fig. 3. Time-evolution of installed hydropower.

- It has the lowest operating costs and the longest plant life, compared with other large scale generating options.
- The fuel (water) is renewable and it is not subjected to market fluctuations up to now.
- Hydropower can definitely contribute to a cleaner environment.

4.1. Hydropower application in Europe

In Europe, the scope for additional hydropower is limited, as most economic sites have already been developed and future expansion is hindered by environmental concerns. Europe only sports so-called ‘‘small hydro’’ (<10 MW), as large hydropower is regarded as being economic and as mature technology, that should not receive market distorting subsides. In some countries governments forbid further development of (large-scale) hydropower due to environmental considerations [24]. More precisely, in Fig. 3, one may find the ‘‘in operation’’ hydropower time-series since 1980 for both Western Europe and the entire planet. According to the data available there is a constant increase of new hydropower installations worldwide, since every year approximately 10.5 GW of new hydroplants come into operation. This is not the case for West Europe, since the corresponding new hydro-capacity remains practically constant during the period examined, slightly exceeding the 153 GW.

European hydropower stations are located in Western Europe (France, Italy, Spain), see Fig. 4. Although in many parts of Europe hydropower development has already passed its peak time, there is still considerable activity both in uprating and refurbishment projects. A total of 2210 MW of new capacity is under implementation in at least 23 countries and more than 8000 MW could be implemented in the near future. The most significant new projects are under way in Bosnia, Bulgaria, Germany, Greece, Iceland, Italy, Norway, Portugal, Romania, Slovenia, Spain and Ukraine.

4.2. Hydropower application in Turkey

Turkey does not have enough primary energy sources such as petroleum and natural gas, but has a huge hydropower potential. Turkey is the second richest country after Norway in Europe for its gross hydroelectric potential which is 440 TWh/year. Technically useable potential is 215 TWh/year, and economic potential is 126.1 TWh/year according to DSIs estimations. Water sources of Turkey are distributed to 26 basins and the total flow rate of water sources for energy production is 186 km^3/years. The distribution of Turkey's hydropower potential on basins according to the calculations of State Hydraulic Works' is given in Fig. 5. The biggest five basins of Turkey are:

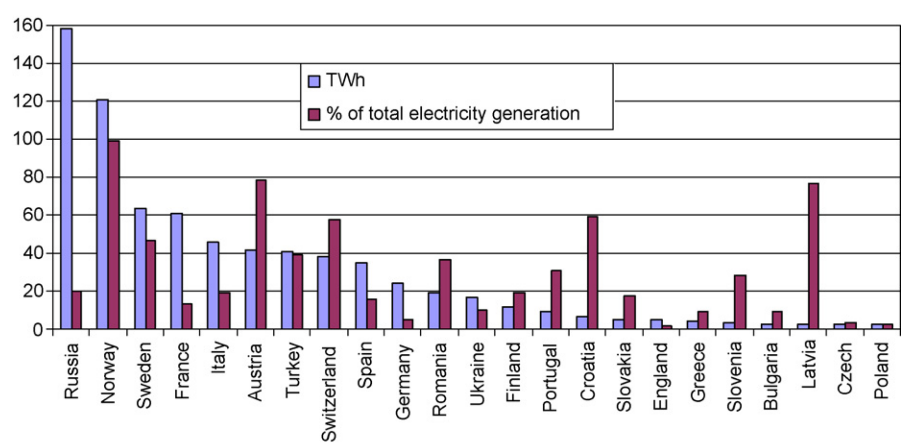


Fig. 4. Annual hydroelectric and % of total electricity generation in Europe.

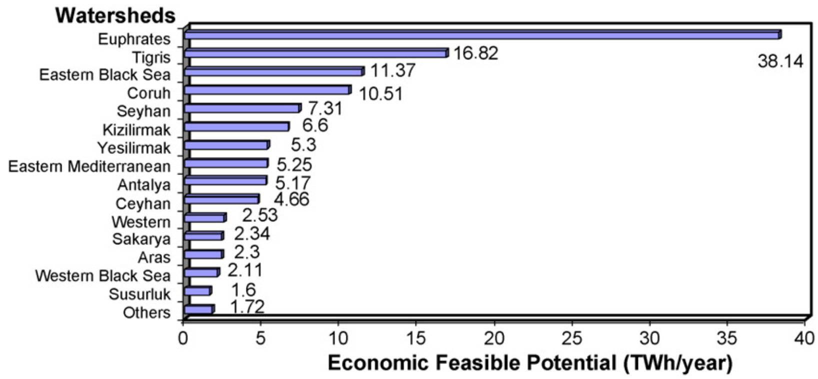


Fig. 5. Distribution of Turkey's hydropower potential on basin level.

- Euphrates: represents over 17% of the national water supply.
- Tigris: represents over 11.5% of the national water supply.
- Eastern Black Sea: represents 8% of the national water supply.
- Eastern Mediterranean: represents 6% of the national water supply.
- Antalya: represents 5.9% of the national water supply.

It is expected that the gross hydroelectric potential of a country does not change with time. On the contrary, economic potential change is depending on the world's and countries' economic situation and the cost of alternative energy sources. Therefore, the plants which are not economic at a time can become economic in the future. Fig. 6 shows the change of Turkey's economic hydropower potential with time. In the year 2002, the economic potential was calculated by DSI as 126.1 TWh/year. But it should be noted that DSI does not take into account capacities under 5 MW in the potential calculations. According to a Turkish private energy company, ERE Elektrik Uretim Sirketi, the hydropower potential of Turkey is about 190–200 TWh/year. The company proposed a specific targeted research project titled ''Assessment of Hydropower Potential of Turkey/Greece Using Innovative IT approach'' (HYDROPOT) to EU within Sixth Framework Programme (FP6) which will clarify the exact hydropower potential of Turkey.

Although Turkey has a big potential for hydropower, only 35% of DSIs estimated economic potential has been utilized so far. According to MENRs projections, Turkey will be generating 103.7 TWh electricity from hydropower in the year 2020. If Turkey uses already 103.7 TWh in the year 2020, the rest 112 TWh will be waiting for the utilization of technical potential. This shows how far Turkey is from European countries' with respect to hydropower utilization. Norway, France and Sweden have already used all their economic hydroelectric potential (HEP) in 2000 and now they are approaching to their technical limits. Table 10 shows technical and utilized potential of some countries. According to that the rate of utilized HEP to technical HEP is only 20.4% in Turkey, whereas this ratio is 98.8% in Sweden.

4.2.1. Projects for hydropower development

4.2.1.1. Importance of hydropower projects for Turkey. Investment in hydropower is recommended to be supported and promoted in the shortest time in Turkey, in order to benefit the economic, environmental, social and strategic effects of hydroelectric power generation. Some benefits of hydroelectric power plants can be given as following:

- Minimum foreign dependency and foreign exchange in the investment.
- Long economic life (75 years).

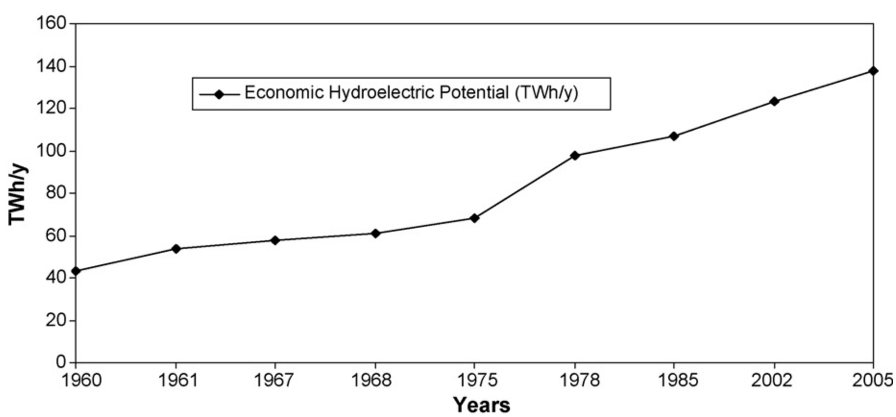


Fig. 6. The change of economic hydroelectric potential of Turkey.

Table 10
Technical (T) and utilized (U) HEP of some countries

Country	Canada	France	Japan	Norway	Sweden	Turkey	USA
T (TWh/year)	5922.9	82	132.4	171.4	80	216	376
U (TWh/year)	332	72	102.6	142	79	44.4	322.1
U/T (%)	56	87.8	77.5	82.8	98.8	20.4	85.7

- Lowest operation cost and no fuel cost.
- Decrease foreign dependency in energy.
- Cheap electricity generation.
- High efficiency.
- The lowest emission levels, the lowest pollution.
- Prevention of erosion through rivers.

In the energy policy of Turkey it is stated that Turkey should diversify energy supplies and avoid dependency on a single source or country. The implementation of this criterion could begin with developing the whole hydroelectric potential of Turkey through promotions and support policies. It has been calculated that the amount of investments needed for the utilization of 150 TWh hydropower potential is US$ 50 billion in Turkey and the shortage of green electricity in EU countries in 2010 is estimated as 200 TWh which requires US$ 165 billion investment. Furthermore, in the year 2020, 300 TWh must either be produced by EU countries or purchased from neighbouring countries. It is recommended by the experts that Turkey utilizes its hydropower potential at the earliest possible time and improves transmission and distribution lines and interconnection system of the country and exports green electrical energy produced from hydro and other renewables to EU countries with considerable prices.

4.2.1.2. Existing and planned hydropower projects of Turkey. According to DSIs 2003 data, Turkey's economic hydroelectric potential is 126,109 GWh that can generate 126 TWh electricity. But, as of 2003, there are 130 HPPs in operation with a total installed capacity of 44,388 GWh and their total electricity generation is 44.4 TWh/year. Hence, Turkey has an enormous task ahead to complete its full hydropower development programme (Table 11). According to DSIs projections, 436 more hydropower plants will be constructed, to exploit the remaining potential of 81.6 TWh/year. In financial terms, it requires an investment of more than US$ 30 billion.

Table 11
Distribution of hydroelectric potential in Turkey

Hydroelectric potential	Number of project	Total annual generation capacity (GWh)	Percent (%)
Master planning is ready	40	9,195	7
Planning is being done	57	7,602	6
Planning is ready	119	22,324	18
Exact project is being done	21	4,494	3
Exact project is ready	19	10,897	9
Under construction	31	10,845	9
Utilization (in operation)	130	44,388	35
First investigation is ready	42	1,180	1
Pre-examination is ready	107	15,184	12
Total	566	126,109	100

DSI declared in the second quarter of 2004 that the number of HPPs in operation increased to 133 with an installed capacity of 44,541 GWh and DSI constructed 81% of HPP (36,239 GWh) in Turkey. Twenty biggest hydropower plants out of 25 were constructed by DSI. DSI is realizing one of the largest water resources development projects in the world which is called GAP (South Eastern Anatolian Project). In the framework of the project, 19 HPPs will be constructed on the Tigris and Euphrates rivers and their tributaries. The total installed capacity of power plants is 26,575 GWh and projected annual energy production reaches 27 TWh. The hydropower plants which were completed in the frame of GAP projects are as follows:

- Atatürk (on Euphrates river, 8515 GWh).
- Karakaya (on Euphrates river, 6386 GWh).
- Birecik (on Euphrates river, 2384 GWh).
- Karkamis (on Euphrates river, 670 GWh).
- Batman (on Batman river, 702 GWh).
- Dicle (on Tigris river, 390 GWh).
- Kralkizi (on Tigris river, 336 GWh).

DSI planned another important hydraulic energy project on Çoruh basin, with a total electricity generation of 8260 GWh. After the completion of all projects 6.4% of Turkish hydroelectric energy production potential will be met through this basin. DSI publishes on its website up-to-date information about HPPs that are in operation, being planned or already planned by DSI, EIE or private companies and can be applied by other legal entities by making Water Usage Agreement. The number of the projects which are developed and applied by legal entities from 2003 up to 3rd quarter of 2004 equals to 55.

Turkey has constructed 555 dams by 2005, which are now in operation. Of these 555 dams, 212 facilities have been constructed as large dams and 343 as small dams (Table 12). To sum up, Turkey has an abundant hydropower potential which makes it the second richest country after Norway in Europe. However, currently only 35% of DSIs estimated economical potential is utilized. Hence, there is much to be done for the utilization of abundant hydropower potential. There are many economically feasible hydroelectric power plants in Turkey, which can be developed without any promotion or support [25]. The only thing needed is to give the confidence to private investors of hydropower projects by removing all regulatory and bureaucratic hurdles.

Table 12
Dam projects in operation and under construction in Turkey [21]

Projects	In operation			Under construction		
	By DSI	Other	Total	By DSI	Other	Total
Large dams	201	11	212	85	1	86
Small dams	343	–	343	124	–	124
Irrigation (million ha)	2.77	2.12	4.89	0.80	–	0.80
Water supply (bcm)	2.50	0.46	2.96	1.09	–	1.09
Flood control area (million ha)	1.0	–	1.0	0.50	–	0.50

5. Conclusions

Today hydropower is the most important kind of renewable and sustainable energy around the world. Hydroenergy is the most reliable and cost-effective renewable energy sources in Turkey. Because of the social and economic development of Turkey, the demand for energy is growing rapidly. Turkey has no big oil and natural gas reserves, but has an abundant hydropower potential to be used for generation of electricity. It can be concluded that:

- Turkey has a huge potential for hydro, wood and other renewables. But the utilization of this potential is a question of determining and implementing sound, long-term energy planning and politics that will prepare the best and reliable environment for the national and international investors.
- Money and technology are the crucial factors for realizing energy investments. That is where national and international private companies may enter the game. Turkey has an appealing energy demand growth. Contribution of international companies that will make investments on energy sector and engineering-consulting companies will bring know-how and solutions can help the development of the energy sector and the country.

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